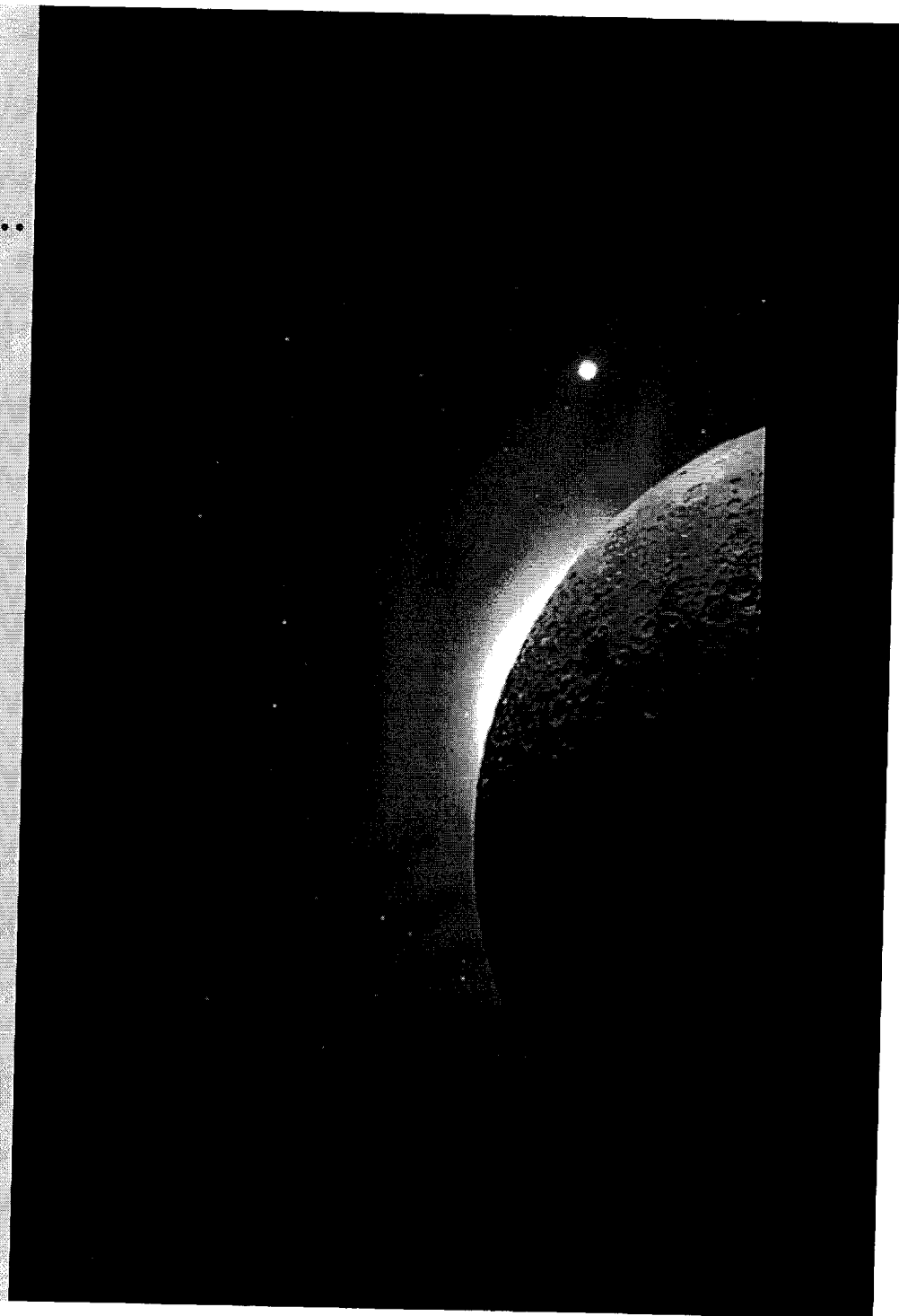


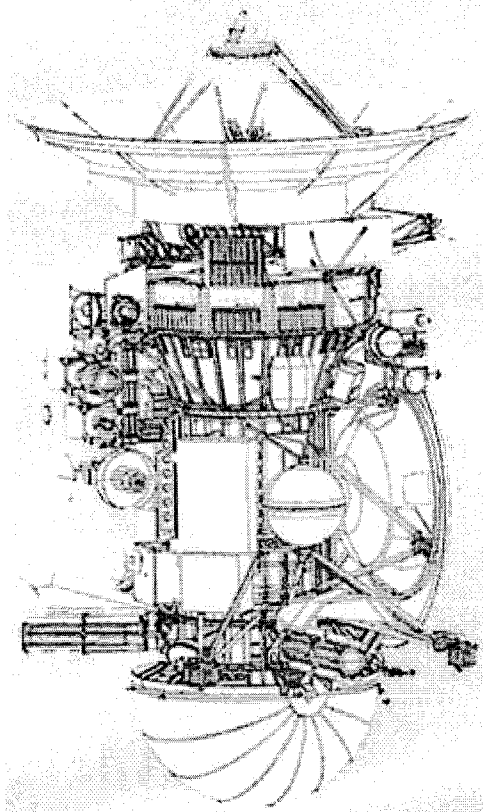
Role of Small Spacecraft in Planetary and Space Exploration

.....
Charles Elachi
JPL / Caltech

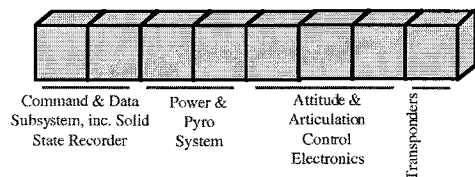
..... August 22, 2000



22.3 ft (6.7 m)
Cassini S/C

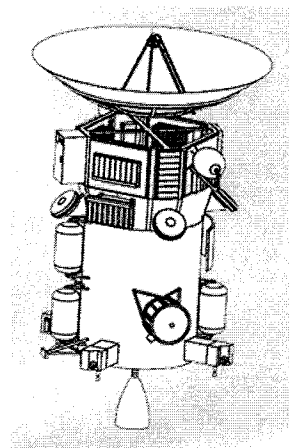


Cassini Bays



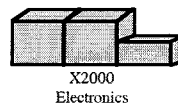
Miniaturization

*Modern long-life, highly-reliable spacecraft:
X2000 contribution*



11.4 ft (3.5 m)
Europa Orbiter S/C

X2000 First Delivery Chassis



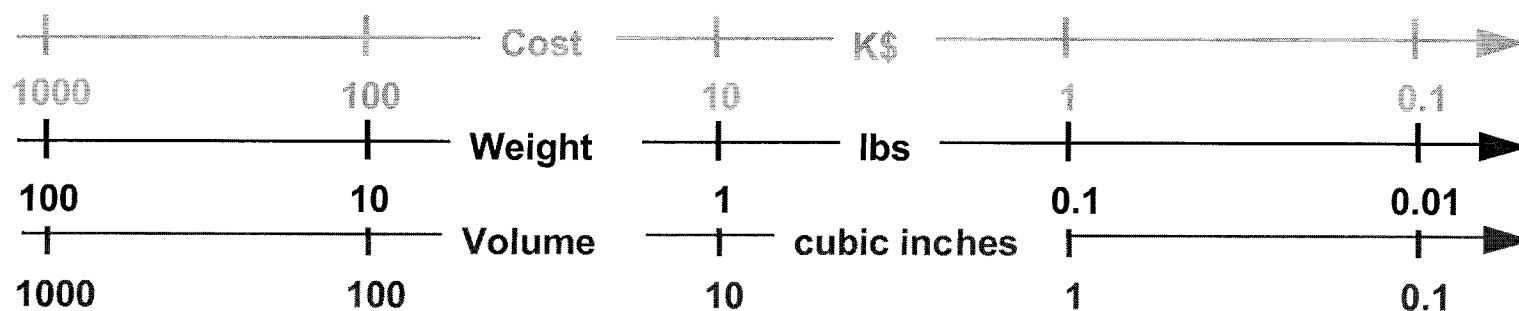
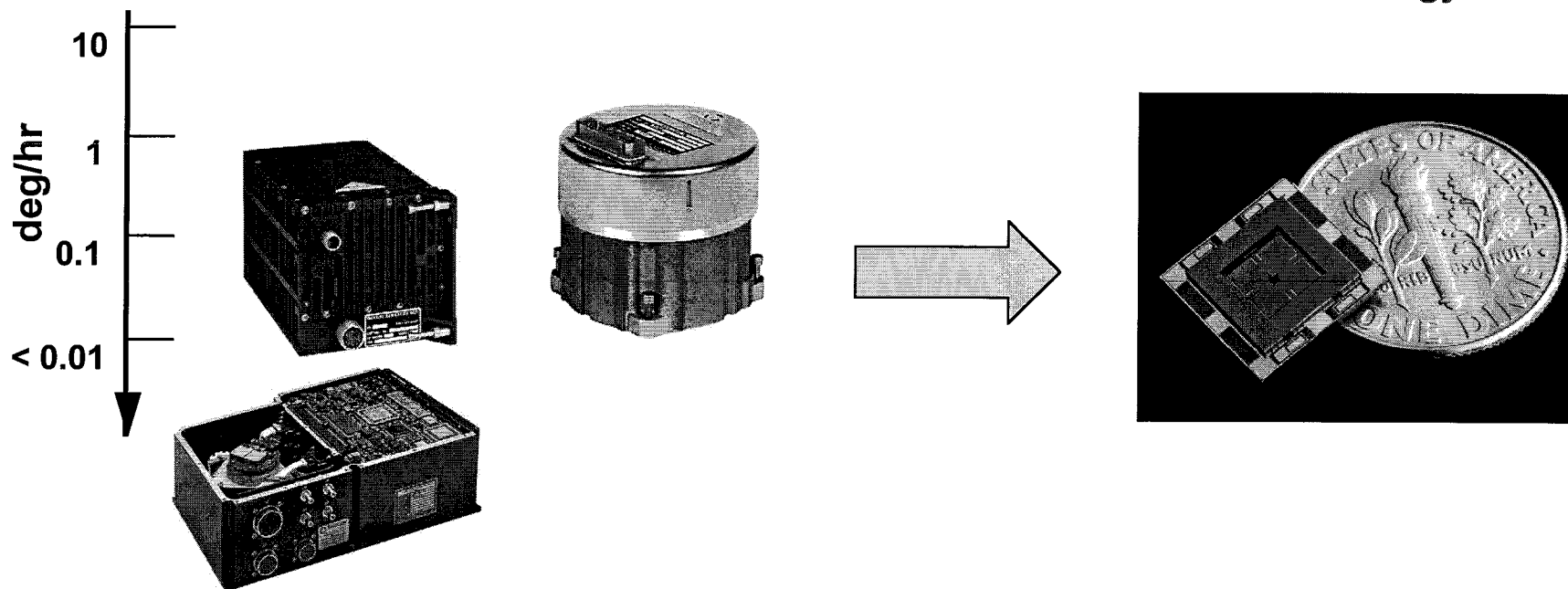
	CDS, inc. SSR	PPS	AACS Electronics	Transponders	Packaging/ Structure	Total	X2000 Electronics
MASS	59.2	45.4	20.9	18.3	54.1	198.0	56 kg
POWER	69.0	36.7	31.4	17.3	0.0	154.4	120 W
VOLUME	0.072	0.072	0.108	0.036	N/A	0.288	0.074

Plus Shielding (28 kg)
Orbit insertion
cubic meters

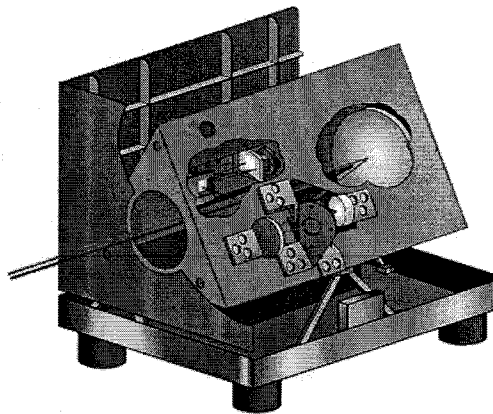
Micro-Inertial Reference System (μ IRS)

Conventional gyro technologies

MEMS micro-gyro

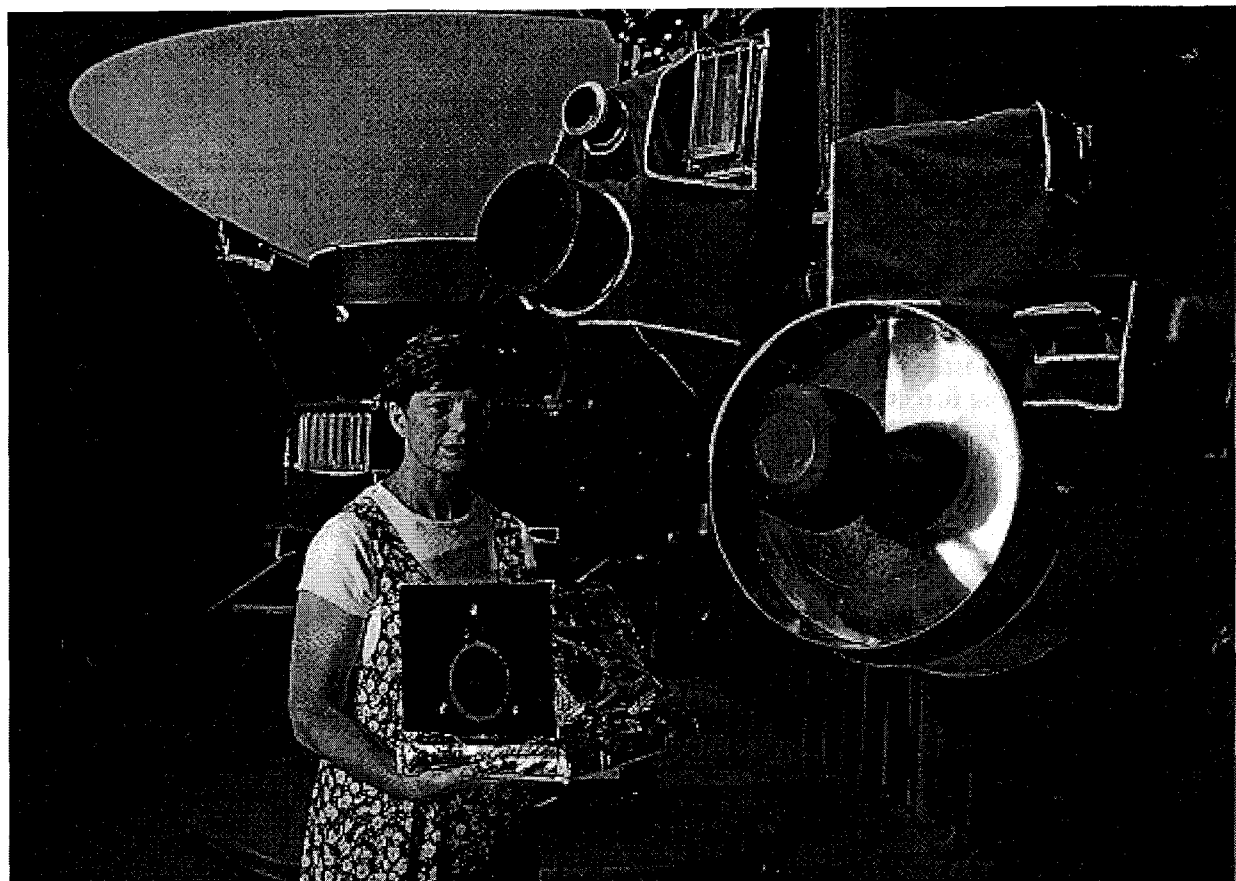


DS1 Miniature Integrated Camera-Spectrometer (MICAS)

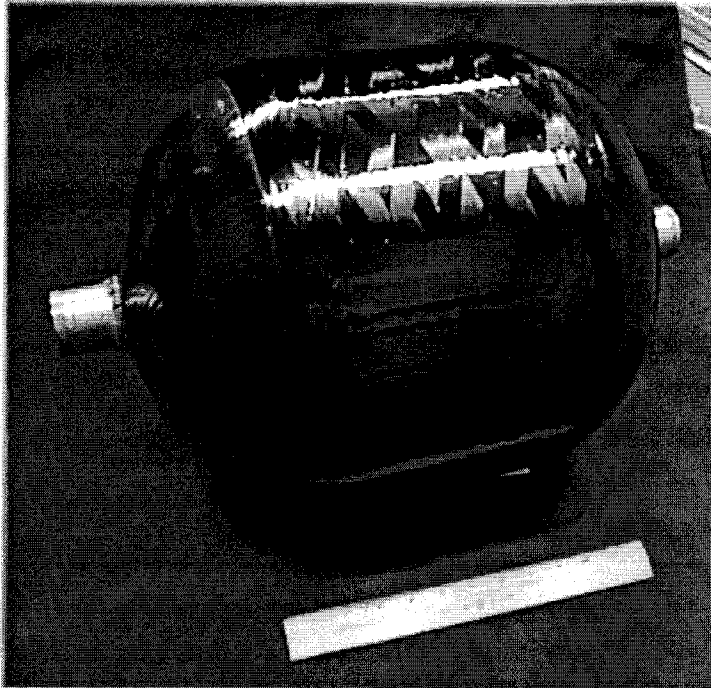


<u>Resource</u>	<u>Today's Constraints</u>	<u>Historical Average</u>	<u>MICAS</u>
Mass (kg)	< 10	~100	7
Power (W)	< 10	~100	6
Cost (\$M)	< 30	~100	< 15

MICAS Compared to the Voyager Remote Sensing Instrument Suite



Ultralight Linerless Composite Pressure Vessels and Conformal Tanks



• PRODUCTS

- Ultralight linerless composite pressure vessels for storing propellants for spacecraft
 - Next generation technology for Propellant and pressurant tanks
 - PV/W up to 3,500,000 for propellant tanks, 7,500,000 for pressurant tanks
- Ultralight toroidal (and/or other shapes) composite tanks for storing propellants for spacecraft
 - Allows propellant and pressurant tanks to be more compact and space efficient
 - Provides the capability to fit tanks in non-standard spacecraft bus configurations easily

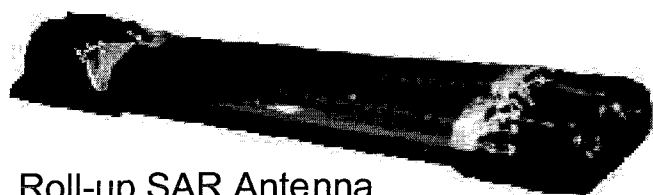
• Performance Metrics

<u>Metric</u>	<u>SOA</u>	<u>Goal</u>
Mass	1	0.25
Cost	1	0.25
Volumetric Eff.	1	0.5
Development Time	1	0.6

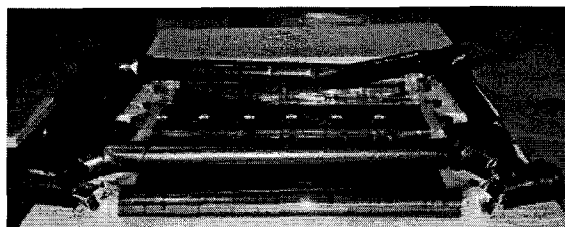
FY	01	02	03	04	05	TOTAL
\$M	0.50	0.75	0.78	0.97	1.0	4.0
TRL	1	2	3	4	5	
			Develop Tooling and Fabrication Methods, Select Materials			
			Testing, Evaluation Refinement			
			Demonstrate Prototype Performance in flight-type environments			

Roll-up Inflatable Membrane SAR Antenna

Characteristics



Roll-up SAR Antenna
(stowed)

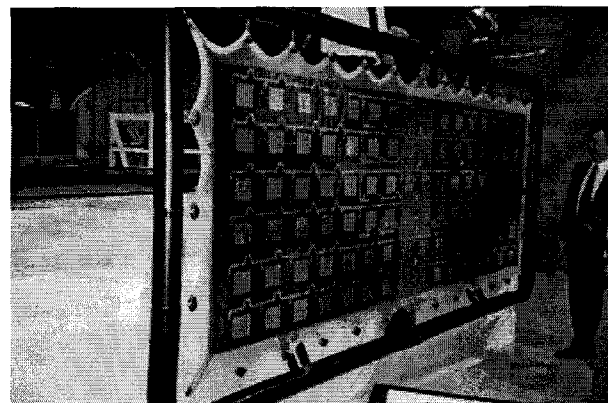


Roll-up SAR Antenna (partially deployed)

- Roll-up inflatable planar frame structure
- Inflatable/rigidizable reinforced aluminum laminate boom
- 3 layers of stretched membrane to form RF aperture (5 micron copper on 2 mil Kapton)
- T/R module distributed on central support for 1-D scanning
- Frequency: 1.25 GHz; Bandwidth: 80 MHz
- Polarization: dual linear
- Gain: 26.7 dB; Efficiency: 74%
- $< 2 \text{ kg/m}^2$ mass density

Benefits

- Mass reduction from 23 kg/m^2 to 2 kg/m^2
- High reliability deployment
- High packaging efficiency/small launch vehicle
- Low production cost
- Applicable to most SAR missions
- Scalable to other frequencies up to Ka-band

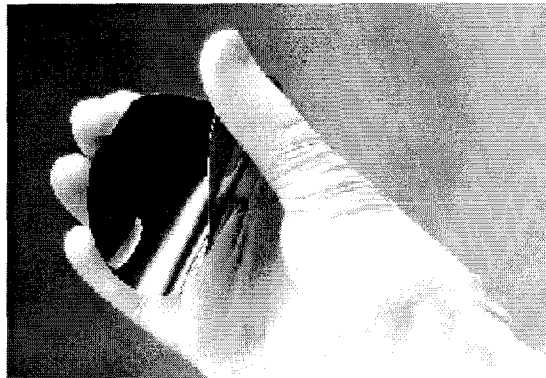


Roll-up SAR Antenna (deployed)

Membrane Compatible T/R Module



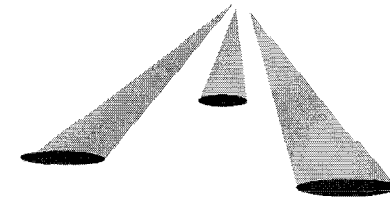
Inflatable membrane antenna



Flexible T/R Module

Characteristics:

- MEMS device fabrication on flexible Si
- MEMS micro heat pipes
- High-efficiency Class-E SSPA
- Fiber-optics embedded in membrane



Benefits:

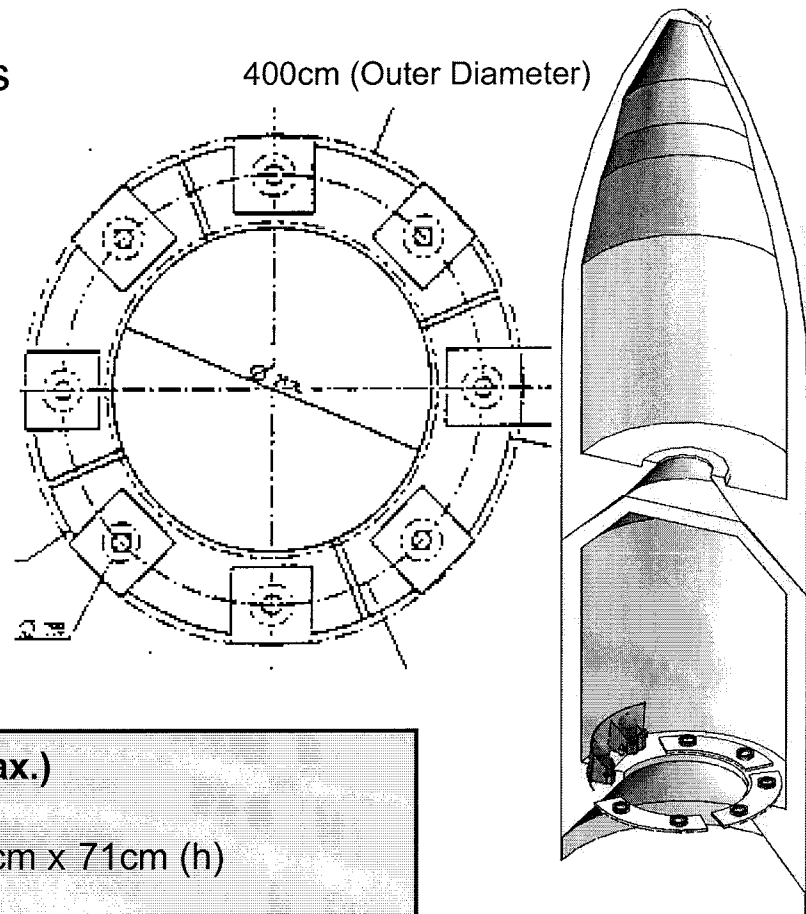
- High efficiency T/R with local thermal management
- Low-cost manufacturing process
- Agile 2-D beam scanning
- Phase correction

New Capabilities:

- High-resolution, wide-swath
- Rapid response
- Digital beamforming
- Very large apertures

ASAP5 Configuration

Micromission S/C is compatible with Ariane-5 dual/triple primary payload configurations (SPELTRA and SILDA5)

**Micro-satellite (8 max.)**

- Mass: 120 kg
- Volume: 60cm * 60cm x 71cm (h)

Twin/Banana Micro-satellites (4 max.)

- Mass: 240 kg
- Volume: 60cm(r) * 71cm (h) * 80 degrees

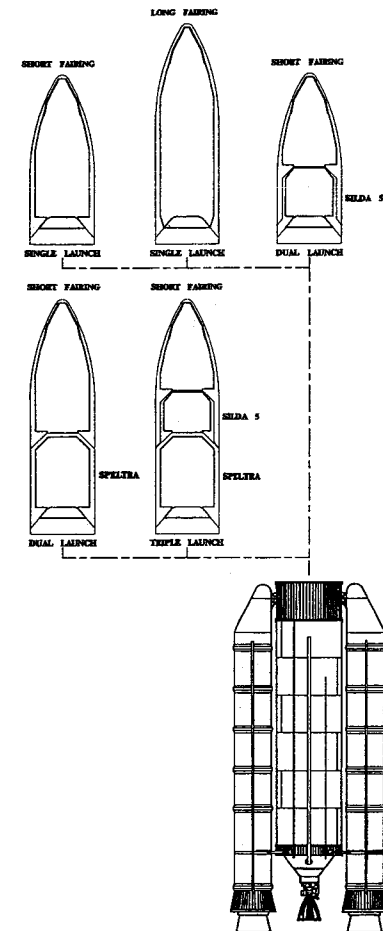
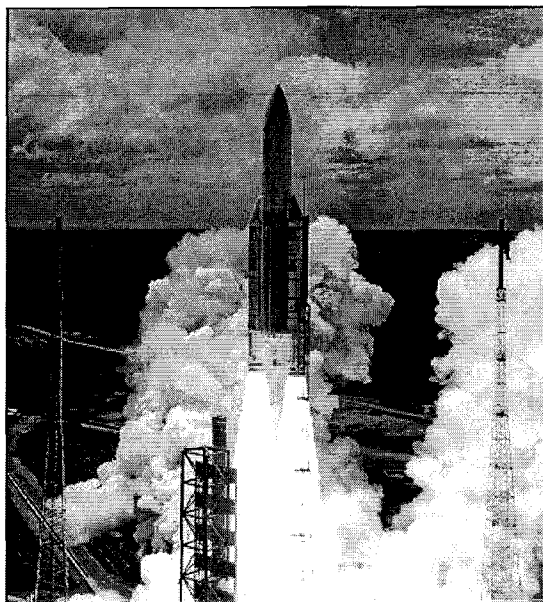


Fig. 2.2

ARIANE 5 Payload Compartment Configurations

Ariane/ASAP Piggybacks

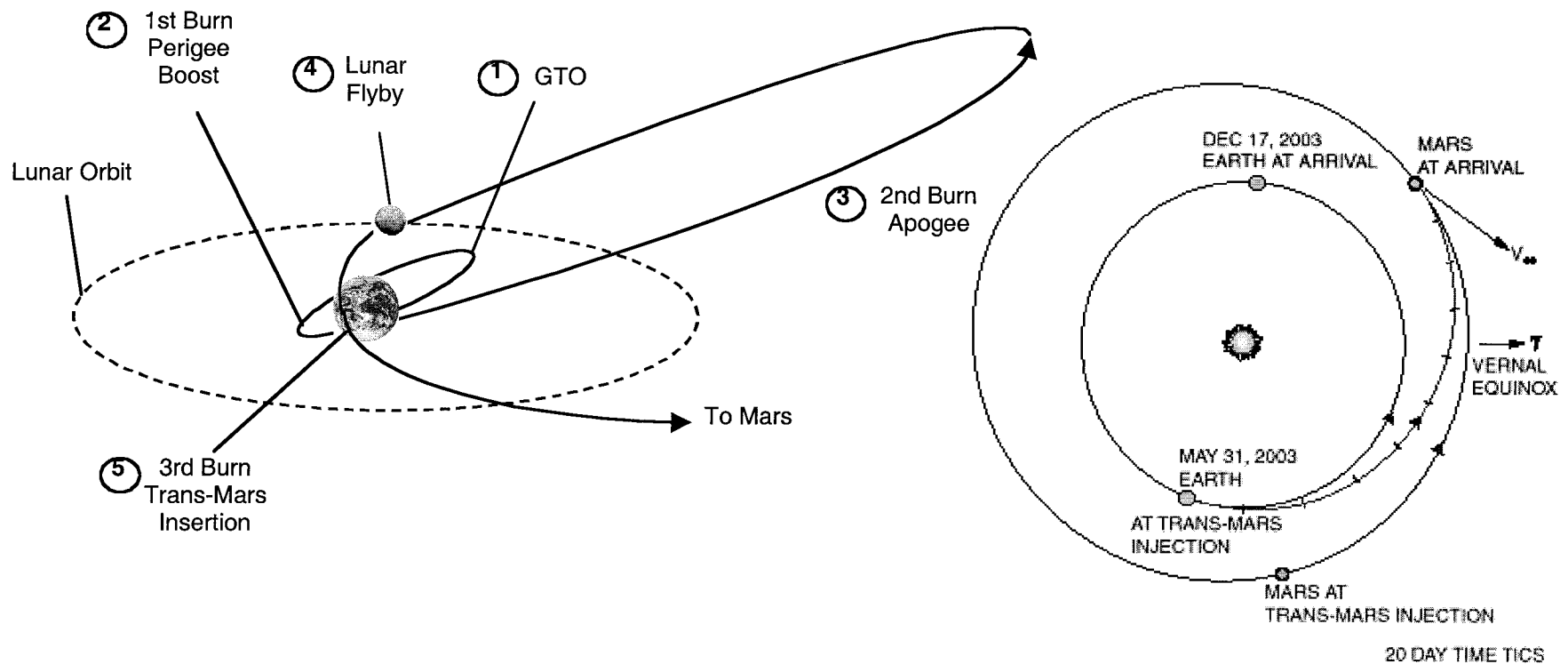
Ariane Structure for Auxiliary Payloads (ASAP) provides a standardized low-cost launch of secondary payloads



- ☐ Low marginal launch cost
- ☐ 3-Months launch period allows launching with commercial GTO missions (6-8 opportunities/year)
- ☐ Approx. 90% of all Ariane launches are to GTO
- ☐ Transparent to the primary passenger - manifest directly with Arianespace
- ☐ Powered off during launch countdown and launch
- ☐ User's Manuals available for ASAP4 and ASAP5
- ☐ Six Ariane-4 ASAP launches to date (21 payloads)
- ☐ First Ariane-5 ASAP launch in Sep/Oct 2000

From GTO to Mars

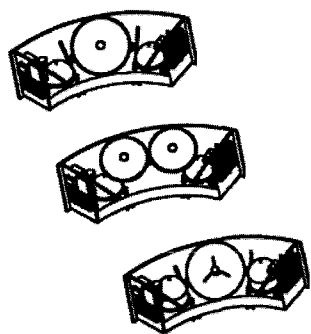
The multi-burn Earth/Lunar flyby strategy allows launch periods of at least 3 Months



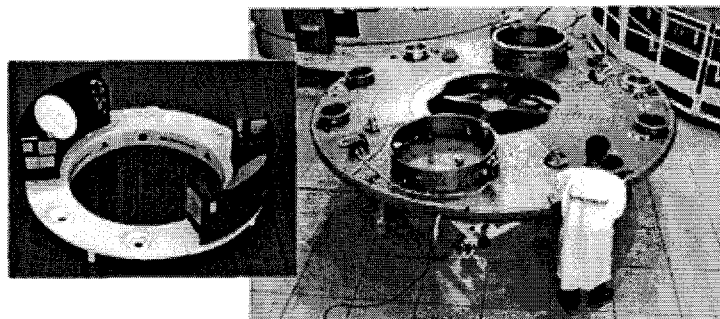
Estimated Payload Capability

Destination	Launch Year	Payload to Approach (kg)	Payload to Orbit (kg)
Mars	2003	45	10
	2005	45 – 50	10 – 15
	2007	50 – 60	15 – 20
Venus	2002	35 – 45	5 – 10
	2004	45 – 55	5 – 10
	2005	50 – 60	10 – 15
	2007	55 – 65	15 – 20
Mercury	2002	15 – 25	None
	2004	5 – 15	None
	2005	10 – 20	None
Main Belt Asteroids	Same As Venus	35 – 60	None
Near-Earth Asteroids	Any	60 – 70	None
Moon	Any	90 – 100	40 – 60

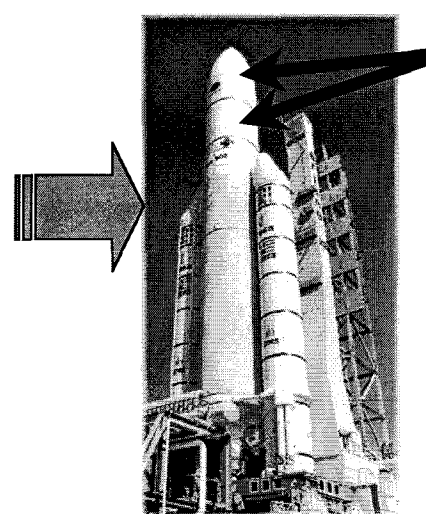
Micromission launch on Ariane-5



Common S/C design for
probe carrier and science
orbiters (240 kg each)

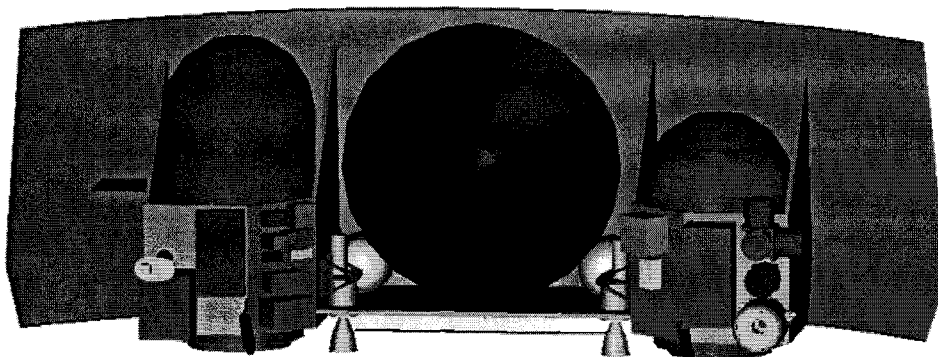


Ariane-5 Structure for
Auxiliary Payloads (ASAP5)



Ariane 5

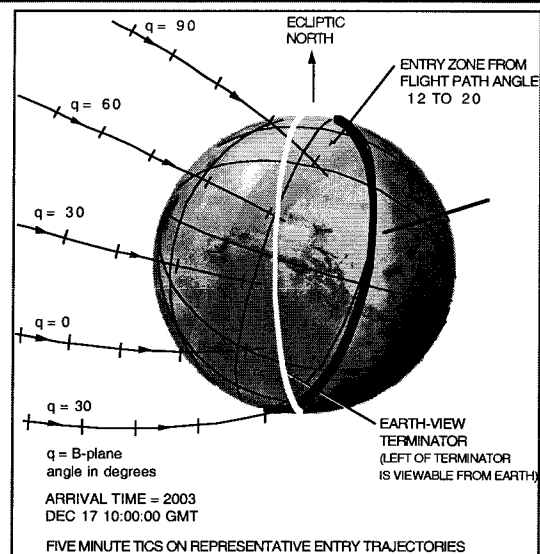
Dual
Primary
GTO
Comsat
Payloads



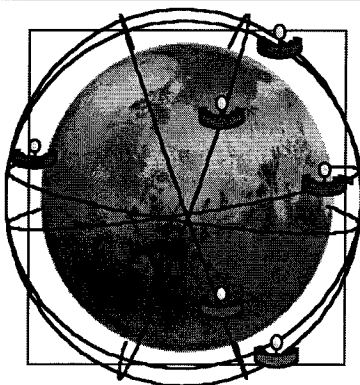
Probe Carrier (Ball Aerospace)

- ☐ ASAP5 secondary launch to GTO
- ☐ 3 month launch period
- ☐ 40-60 kg probes to Mars
- ☐ 6-20 kg instruments in Mars Orbit
- ☐ NASA-CNES cooperation

Probe Carrier Missions

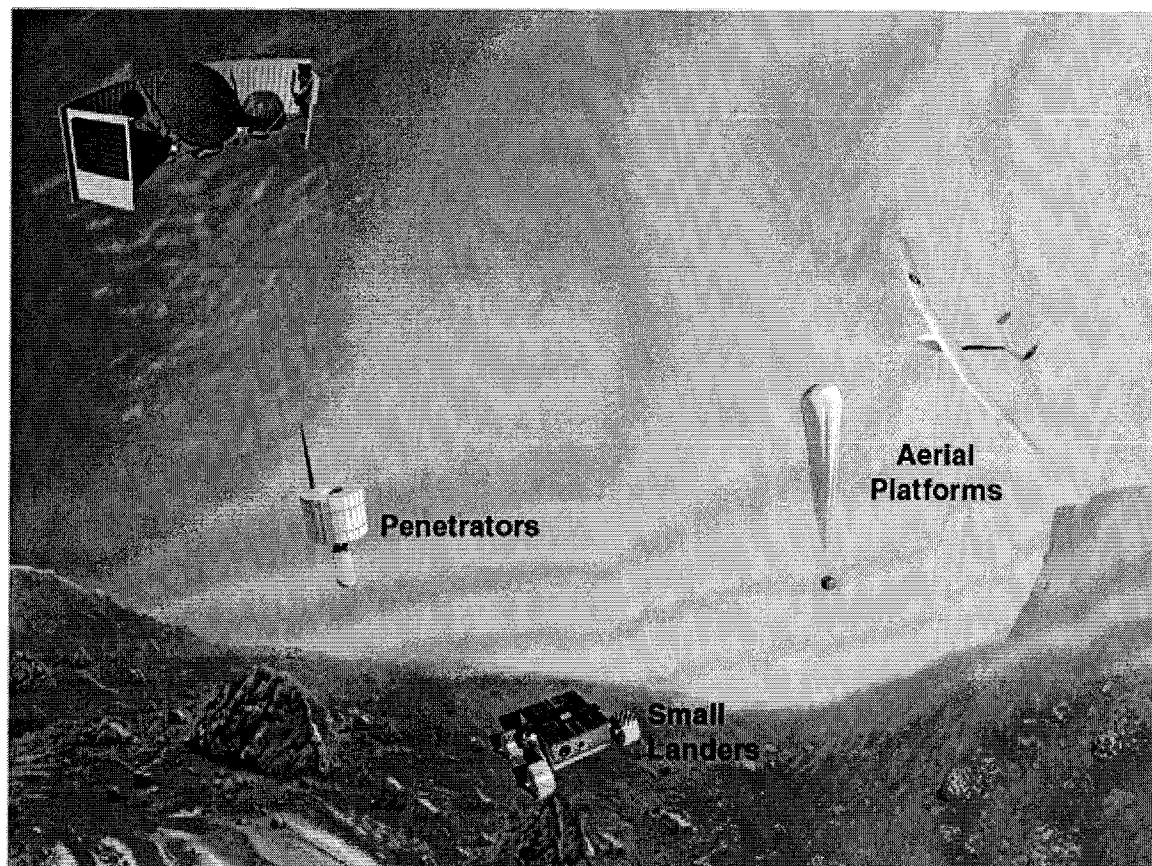


Science Orbiters



Mars Micromission Examples

Small stand alone Mars mission doing focused science mission from orbit or in situ.

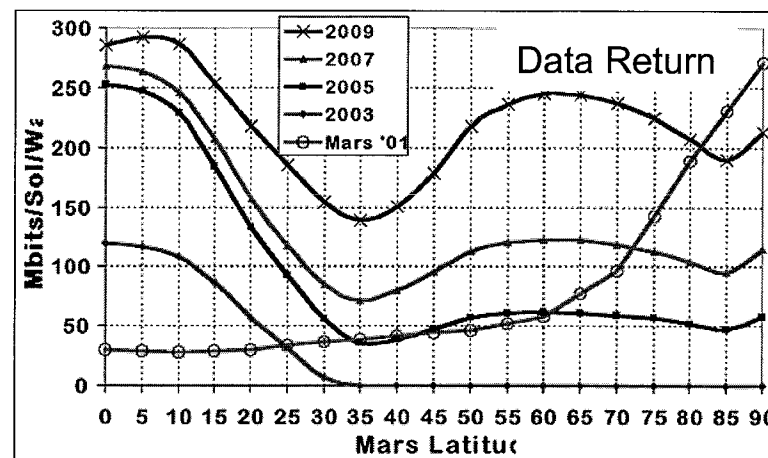


Microsatellite Constellation

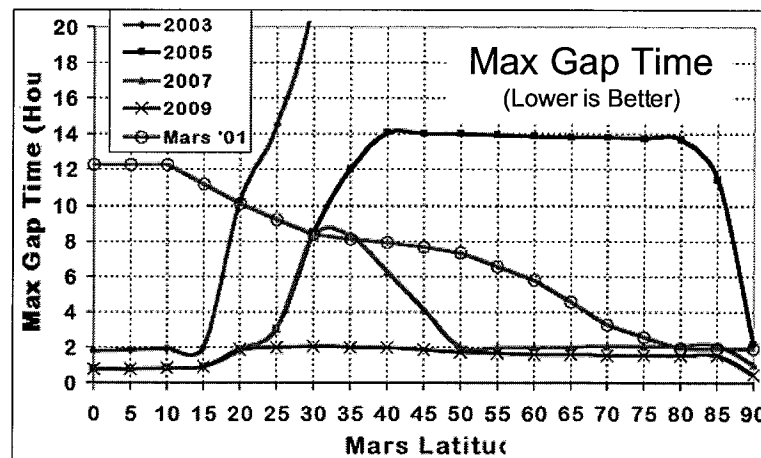
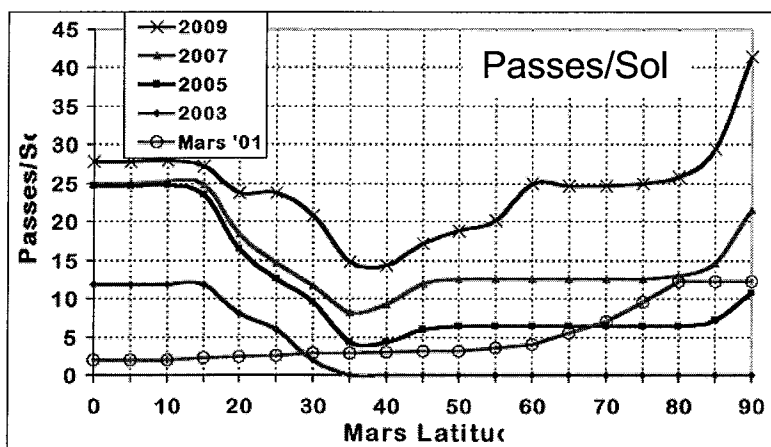
Telecom Performance Evolution Summary

Inject	June '03	Aug '05	Sept '07	Oct '09
MOI	Dec '03	June '06	April '08	June '10
Finish Aerobrake	May '04	Nov '06	Sept '08	Nov '10
ASAP 1	172°, 800km	172°, 800km	172°, 800km	172°, 800km
ASAP 2		172°, 800km	172°, 800km	172°, 800km
ASAP 3		111°, 800km	111°, 800km	111°, 800km
ASAP 4			111°, 800km	111°, 800km
ASAP 5			172°, 800km	172°, 800km
ASAP 6				111°, 800km
ASAP 7				111°, 800km

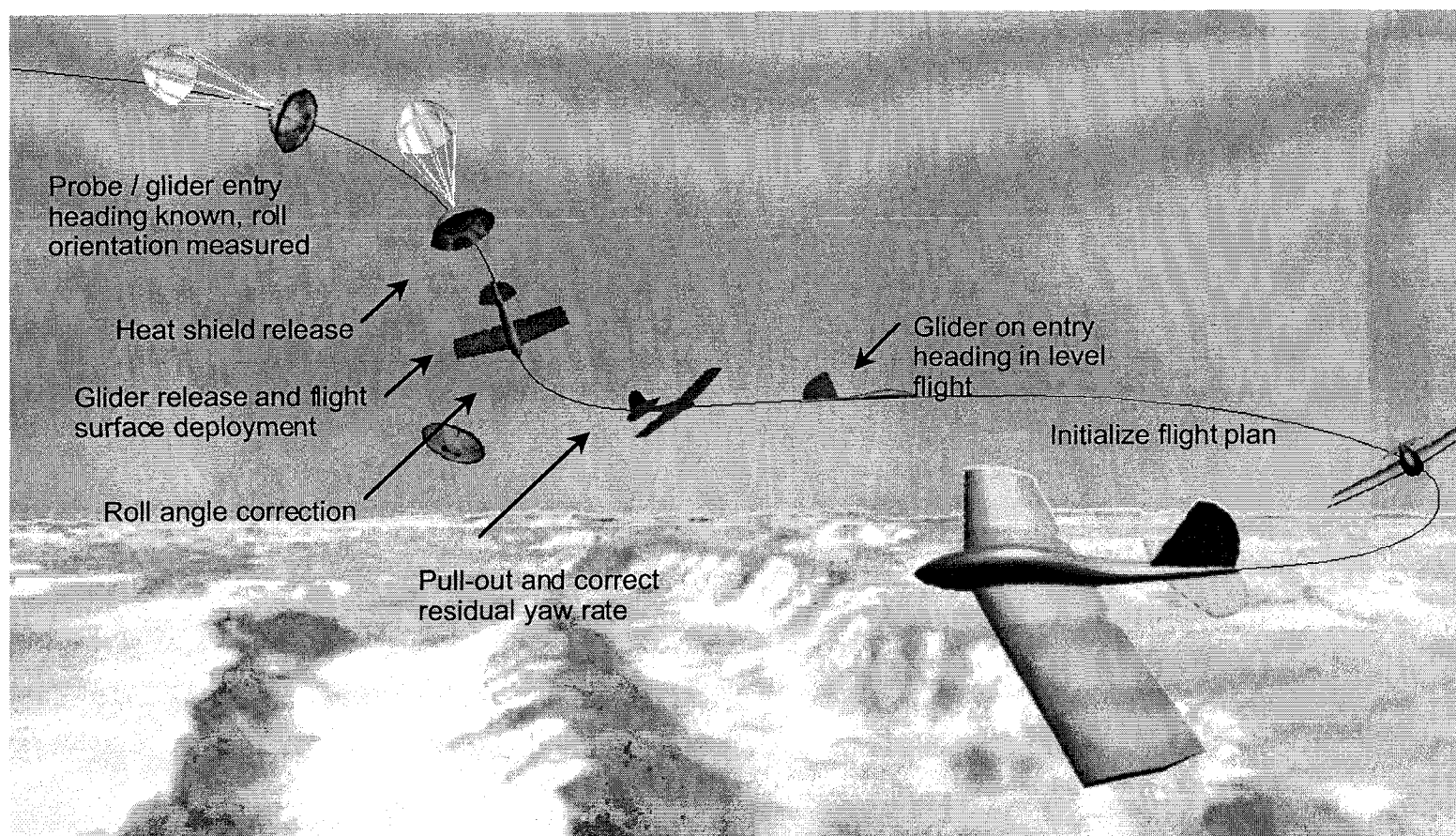
SOAP Generated
Assumes 15° Minimum Elevation Angle



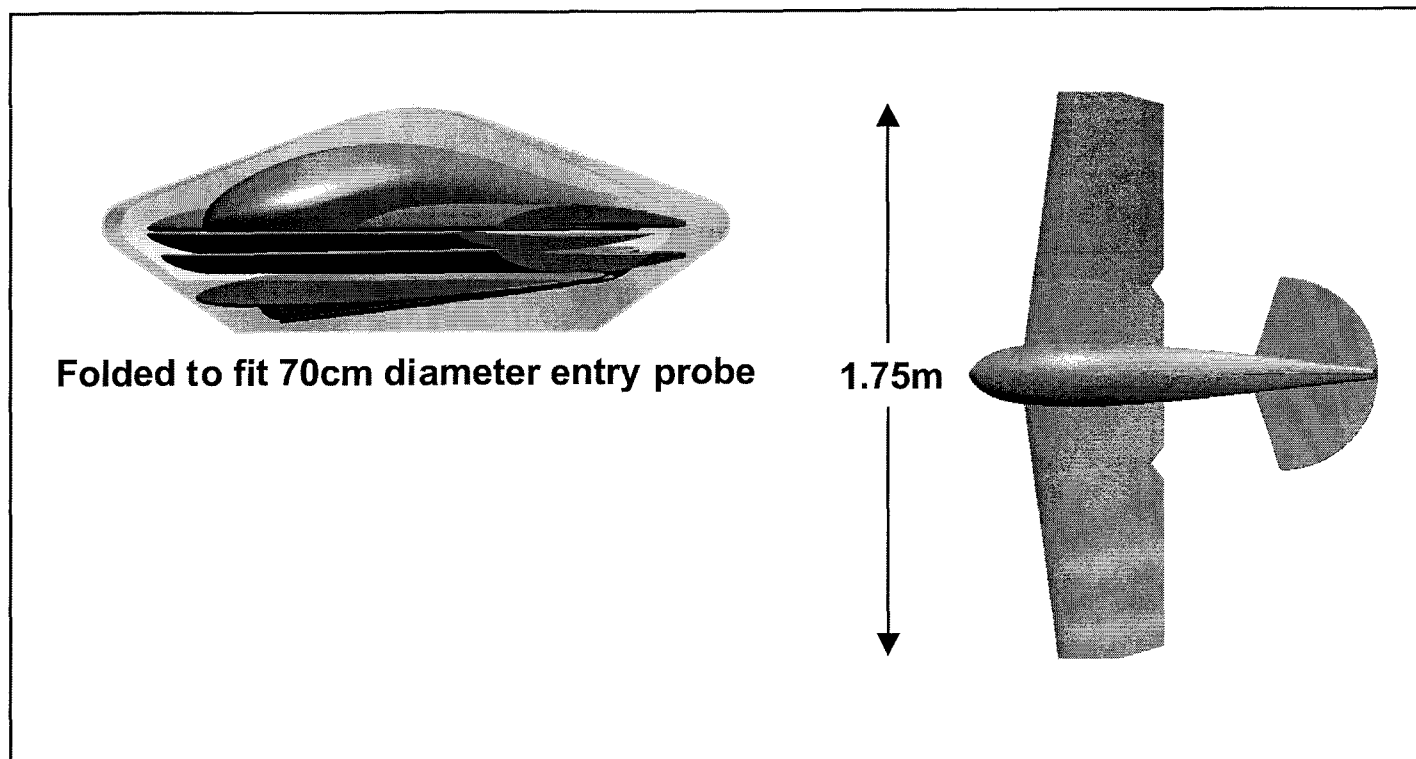
Assumes omni antenna on both ends of the link



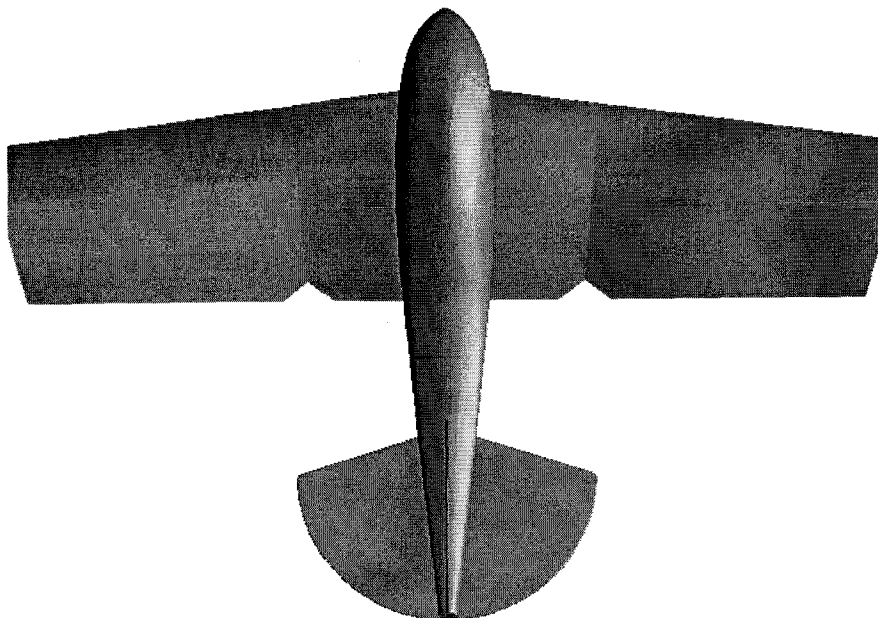
Glider Deployment



Airplane Overview Glider layout

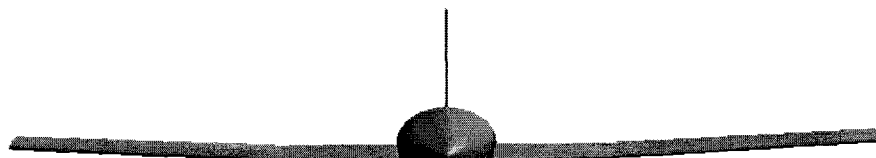


Concept Glider Configuration

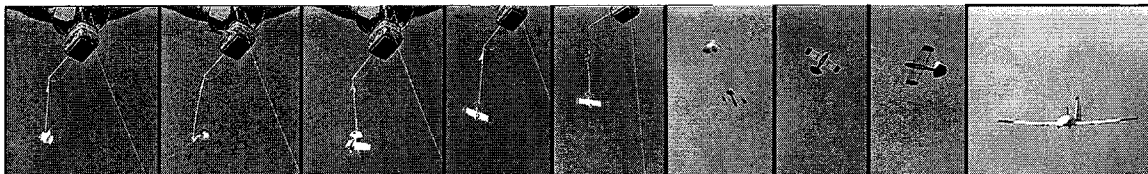
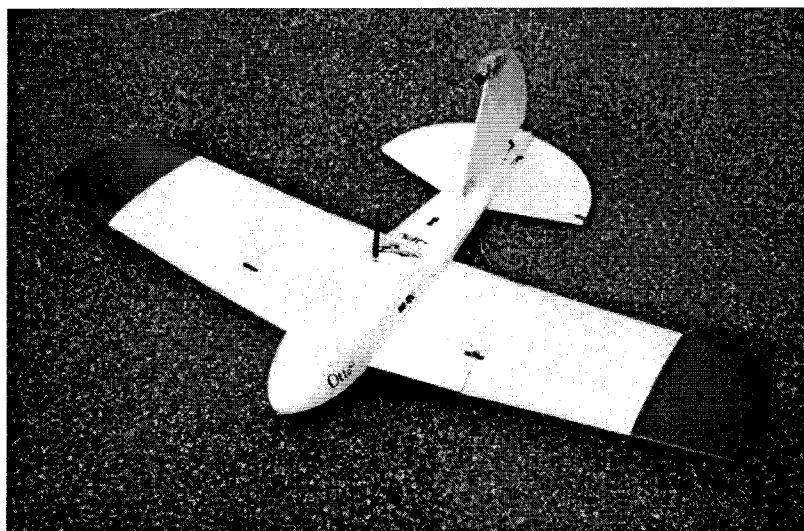


Baseline Geometry & Performance

Wing Span	1.75 m
Wing Area	0.60 m ²
Mean Chord	0.343 m
Aspect Ratio	5.1
Structural Wt.	2.0 kg
Gross Wt. + Reserve	8.5 kg
Flight Speed @ 5km Alt.	108.0 m/s
Sink Rate @ 5km Alt.	12.7 m/s
Mach No. @ 5km Alt.	0.47
Reynolds No. @ 5km Alt.	40,000
Design Lift Coef.	0.90
Max. Lift Coef.	1.25
Turning Radius @ 30 deg bank	7 km
Glide Ratio	8.5 : 1



Glider

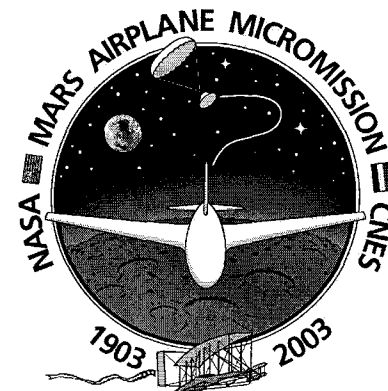
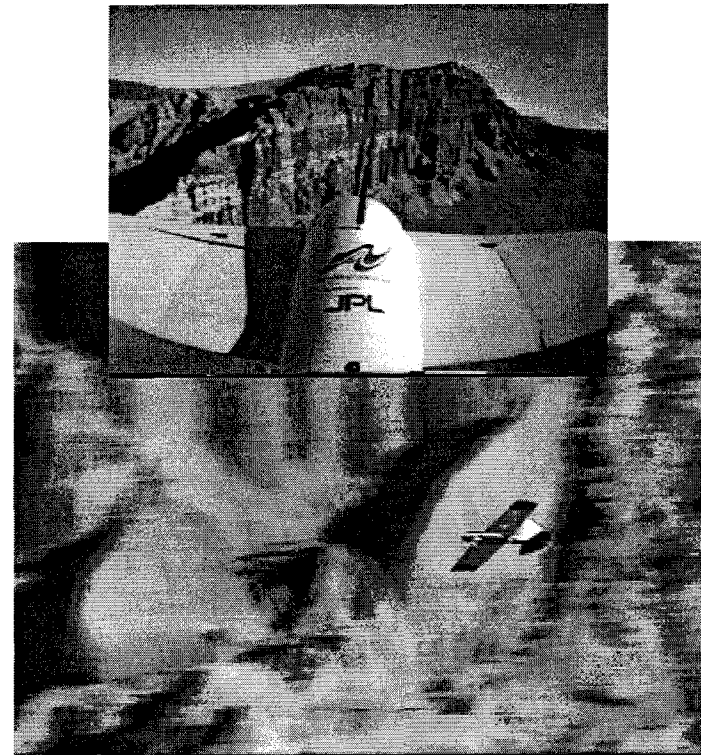


Sponsored by:

JPL

Mars Aircraft/Glider Science

- ☐ High-resolution surface imaging
 - Landing site selection/sample return
 - Rover navigation
 - Geology/geomorphology/exobiology
- ☐ Compositional mapping
 - Surface mineralogy
 - Aqueous deposits
- ☐ Neutron spectroscopy/radar sounding
 - Search for water
- ☐ Electromagnetics/Paleomagnetism
 - Search for water
 - Magnetic anomalies
- ☐ Atmospheric measurements
 - Temperature, pressure, mass and energy transport
 - Atmospheric composition
 - Dust



Piccard: A Mars Balloon-borne magnetometer survey micromission

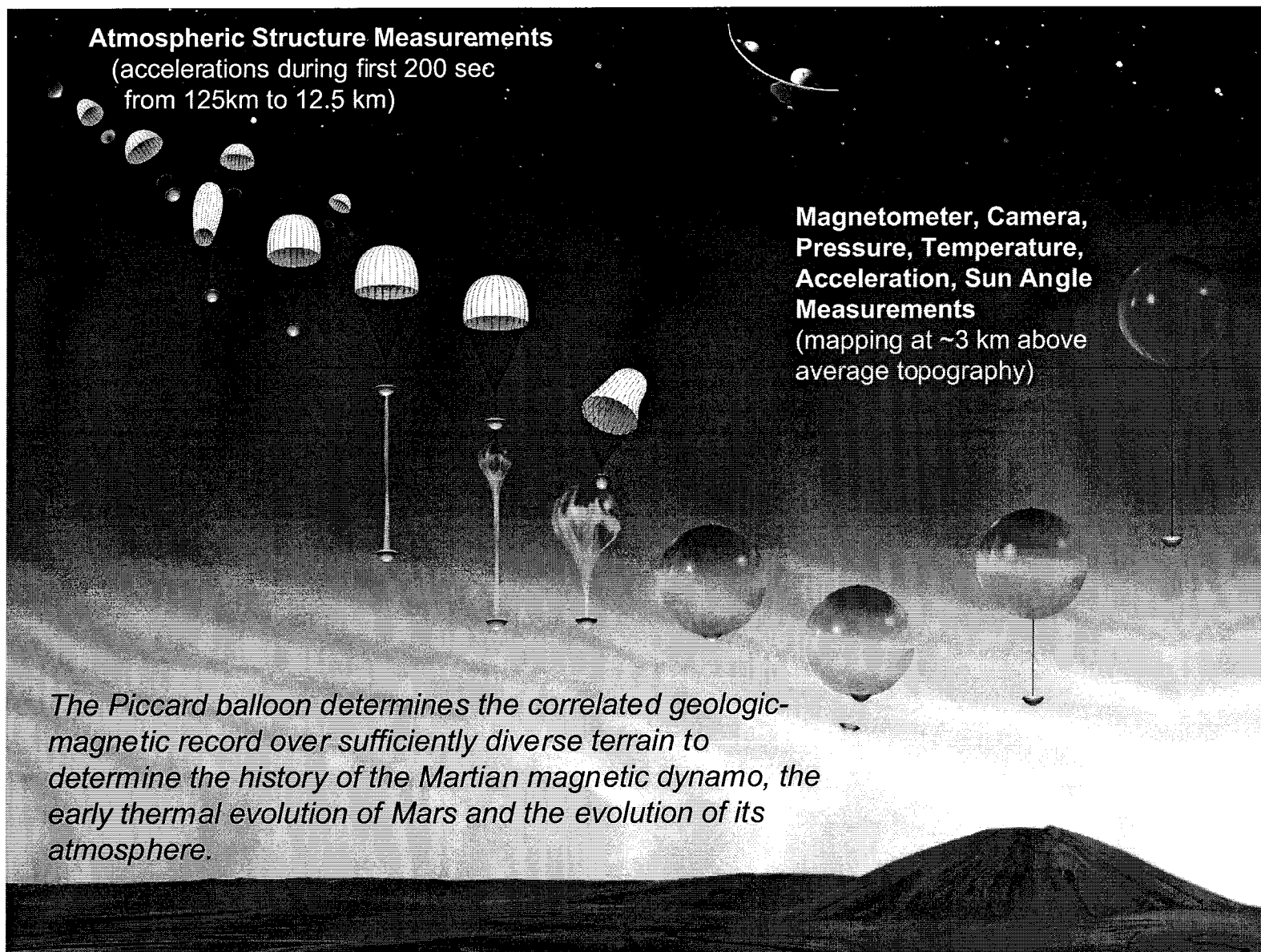
Atmospheric Structure Measurements

(accelerations during first 200 sec
from 125km to 12.5 km)

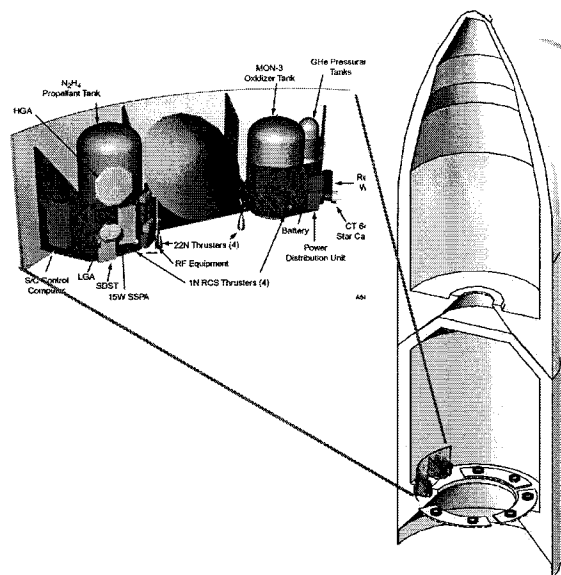
Magnetometer, Camera, Pressure, Temperature, Acceleration, Sun Angle Measurements

(mapping at ~3 km above
average topography)

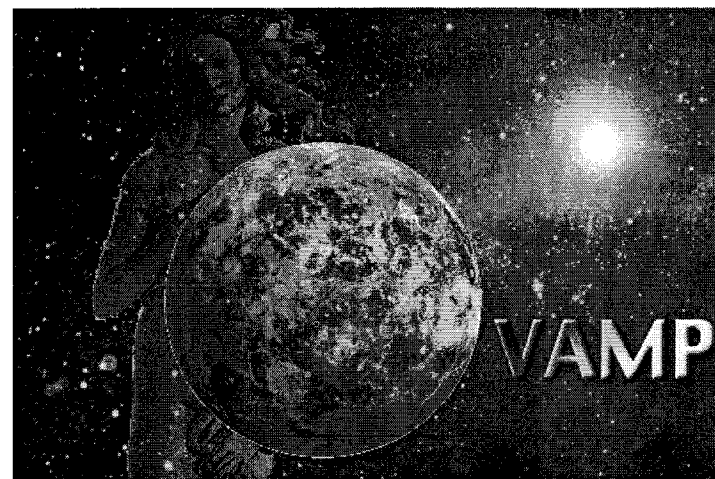
The Piccard balloon determines the correlated geologic-magnetic record over sufficiently diverse terrain to determine the history of the Martian magnetic dynamo, the early thermal evolution of Mars and the evolution of its atmosphere.



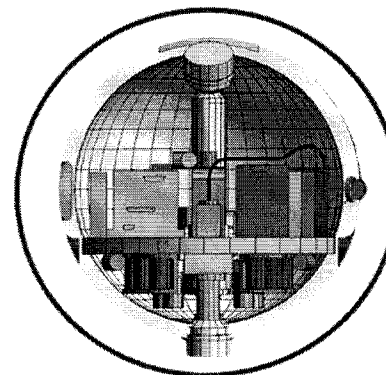
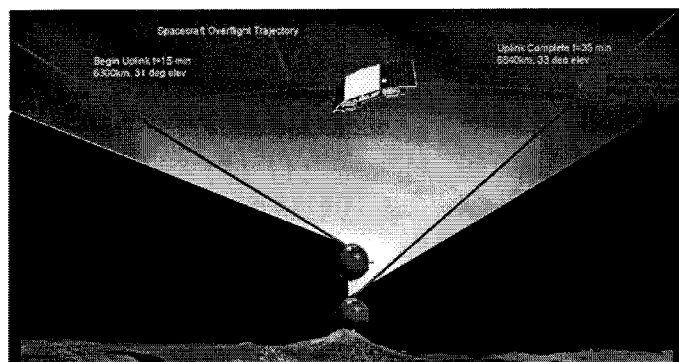
Venus Atmosphere Measurement Probe



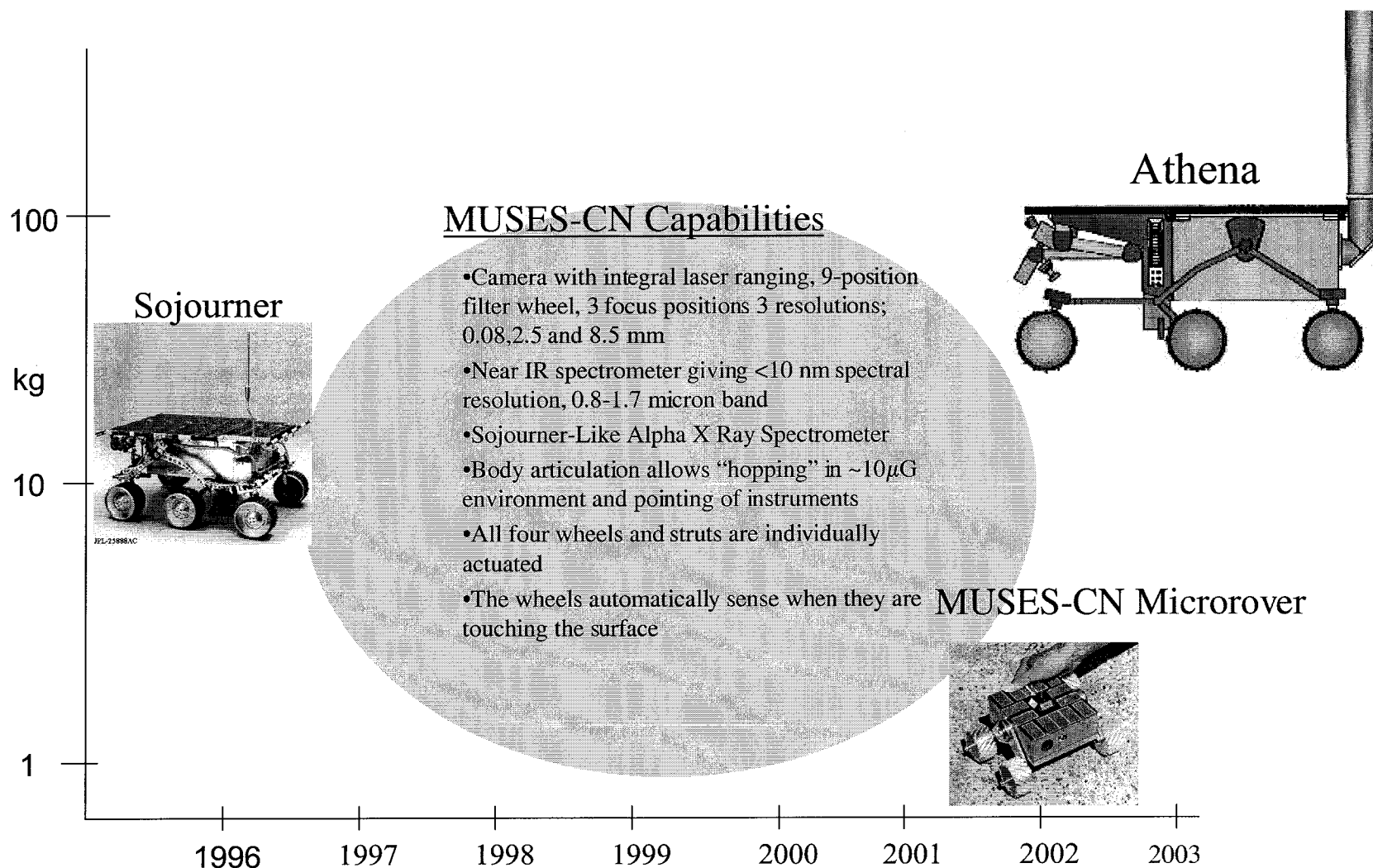
The VAMP mission plans a piggyback launch on an Ariane 5 . . .



. . . and upon arrival at Venus, the spacecraft will release a probe, receive atmospheric science telemetry from the probe and send the data back to Earth.

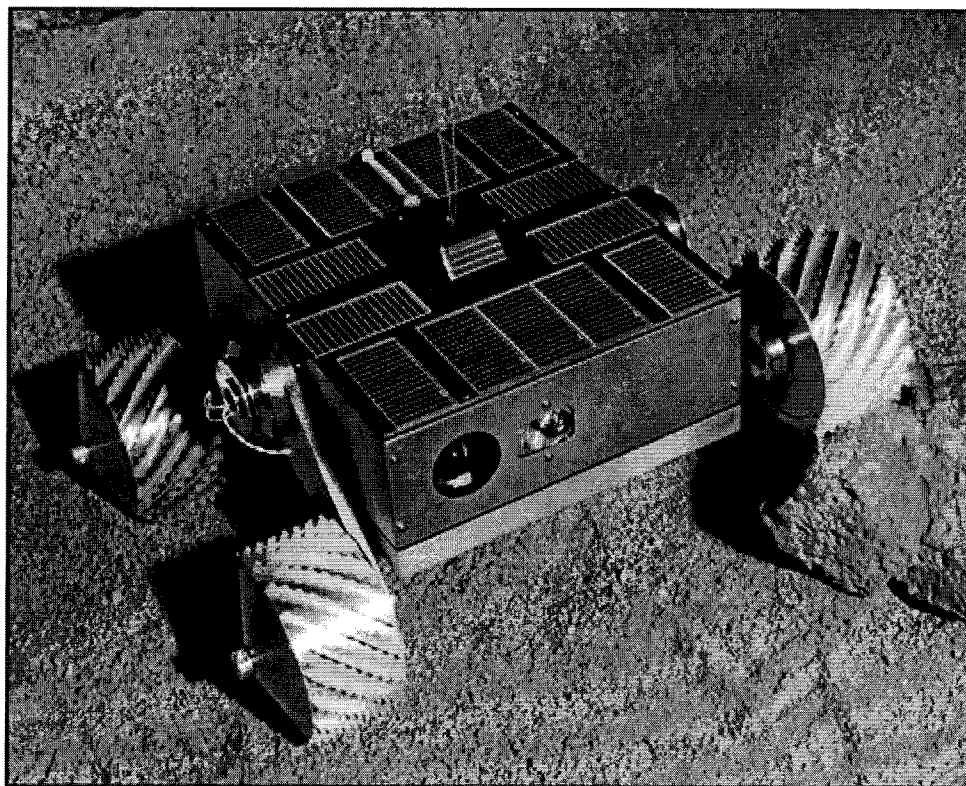


Microrover Comparison



MUSES CN Rover

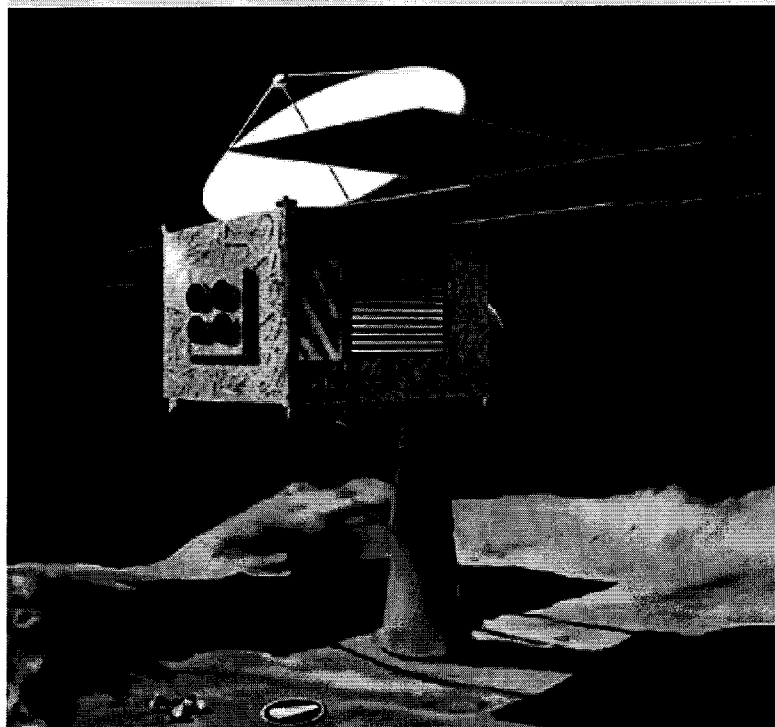
- 256x1 InGaAs detector array giving <10 nm resolution over 0.8-1.7 micron band; RMS noise $< 2\%$ of full scale
- panoramic imaging using a 256x256 detector at 1 mrad/pixel in 9 vis/VNIR spectral bands,
- 3 focus positions/resolutions:
 - 6 m, 8.5 mm
 - 2 m, 2.5 mm
 - .07m, .08mm
- Sojourner Like AXS
- body articulation allows “hopping” in $\sim 10\mu\text{G}$ environment and “posing” of instrument
- Mass 1300 grams
- Size 14 x 14 x 6 cm
- Power Capability 2.3 W (normal incidence)
- Max. velocity,
 - rolling contact, 1.5 mm/s
 - hopping or skimming 10 cm/s
- Data rate 4800 bits per second [20km range]



four 6.5cm dia wheels on 7 cm articulated struts

MUSES CN Project Overview

MUSES C spacecraft landing on the asteroid. MUSES CN rover in foreground.

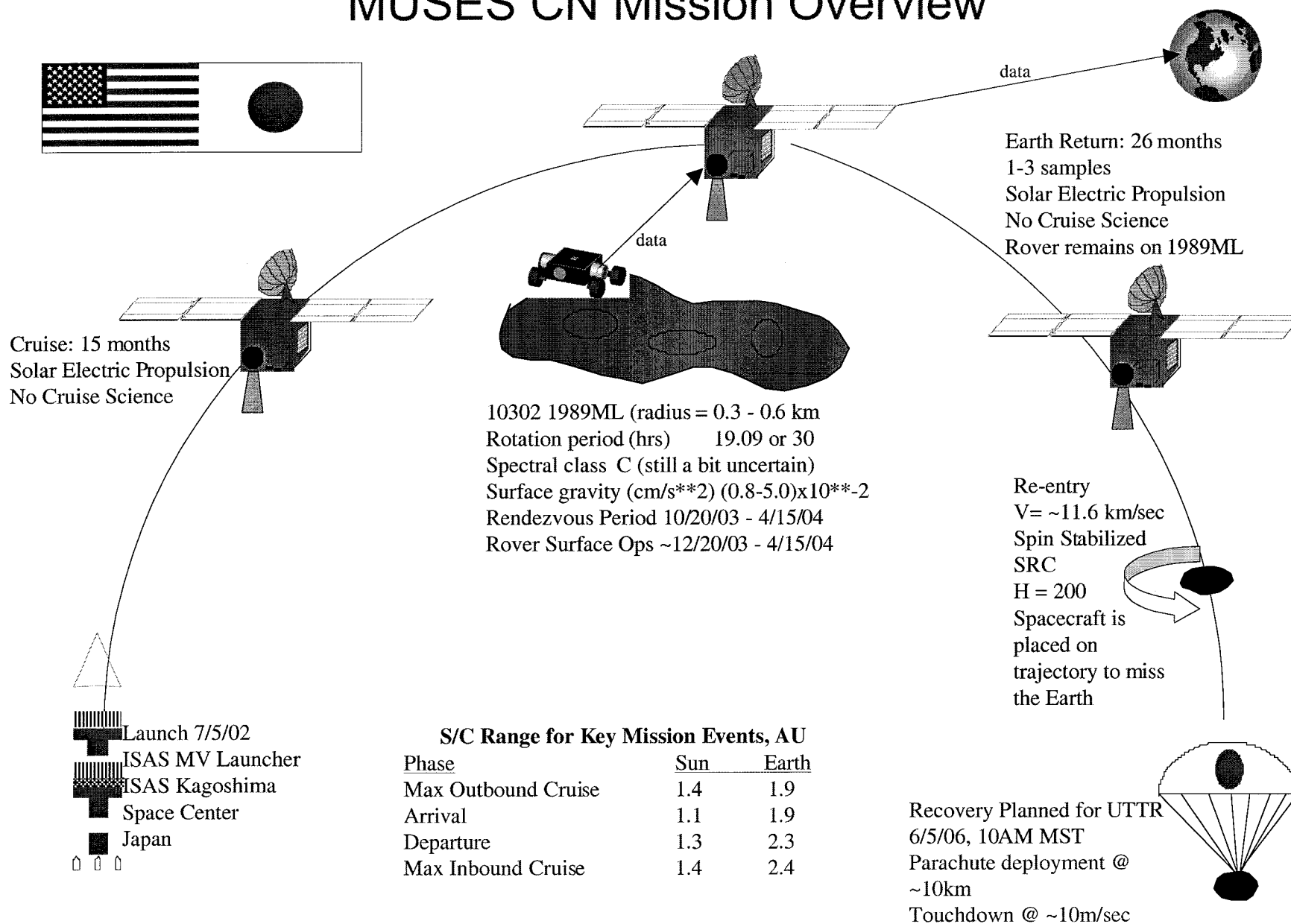


- **Introduction:** MUSES CN is the project which will implement the NASA portion of the NASA-ISAS collaboration on the ISAS MUSES C Asteroid Sample Return Mission
- **Objectives:** 1) develop and demonstrate the rover technology for asteroid mobility and ultra-miniaturization beyond Sojourner and 2) acquire scientific data, both remote sensing and in situ, from one of the many near Earth asteroids including a sample of the surface.
- **Scope of Work:** 1) rover development/delivery, 2) support for science teams, 3) rover and science teams ops at the asteroid, 4) DSN tracking of MUSES C, 5) navigation support for MUSES C, 6) support for ISAS testing @ ARC and 7) recovery of MUSES C sample capsule in US territory.

Schedule:

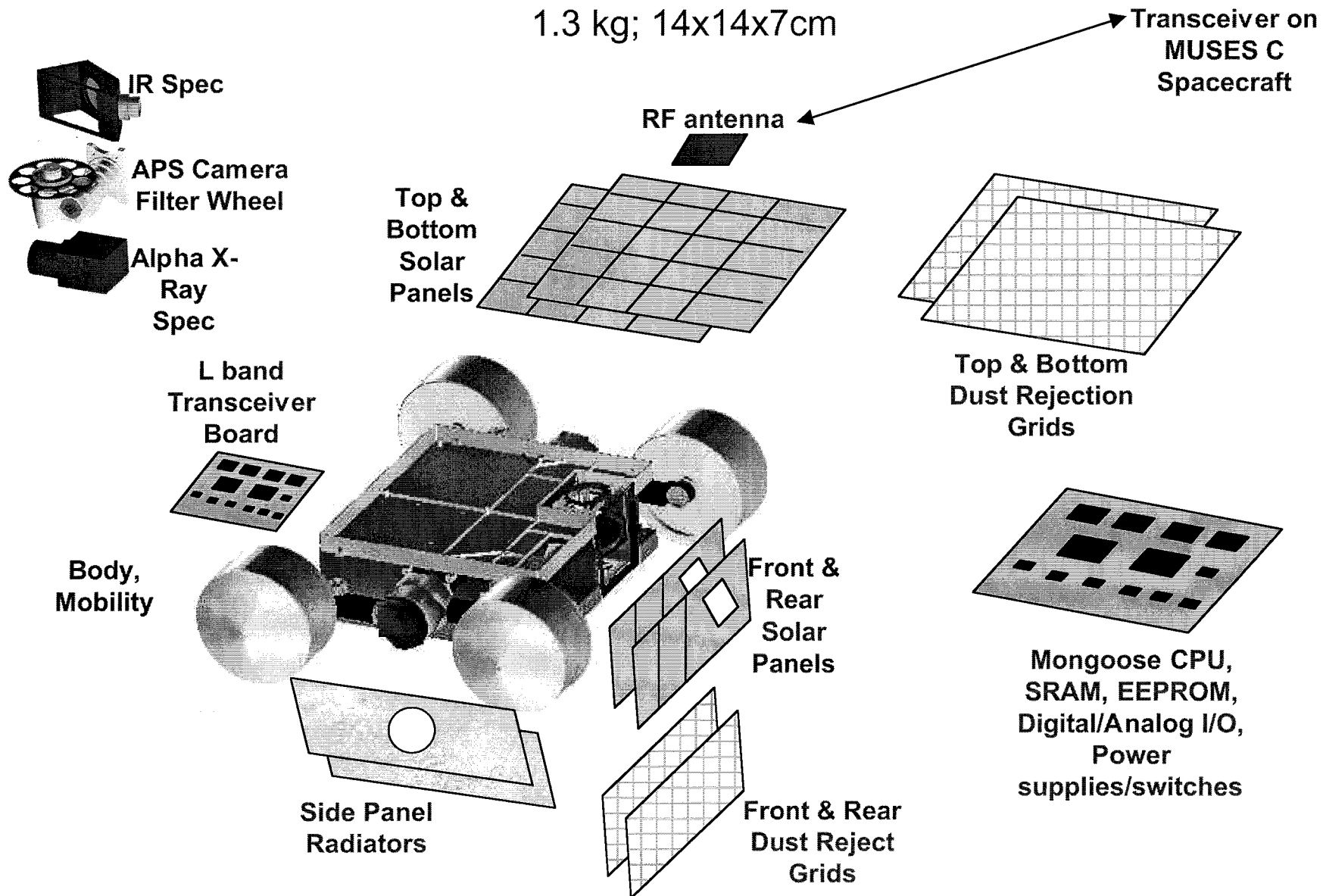
FY 97	FY 98	Development	FY 02	Operations	FY 06
Huntress/Nishida Meeting 5/2/97	Rover CDR 7/99	Rover Delivery to ISAS 8/01	Launch 7/02	Rendezvous 10/03	Sample Recovery 6/06

MUSES CN Mission Overview

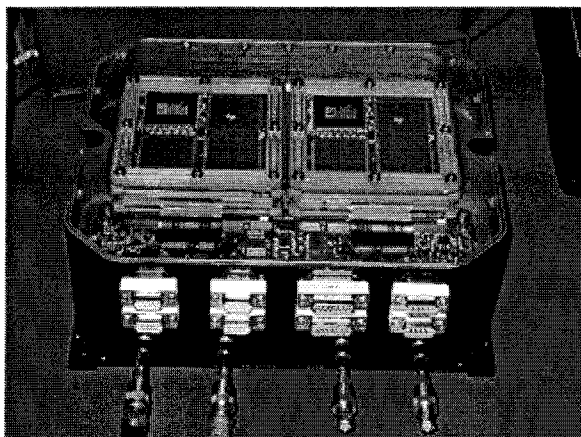


MUSES CN Rover Functional Diagram

1.3 kg; 14x14x7cm



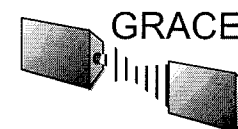
The BlackJack Scientific GPS Flight Receiver



The BlackJack: 20 x 20 x 9 cm

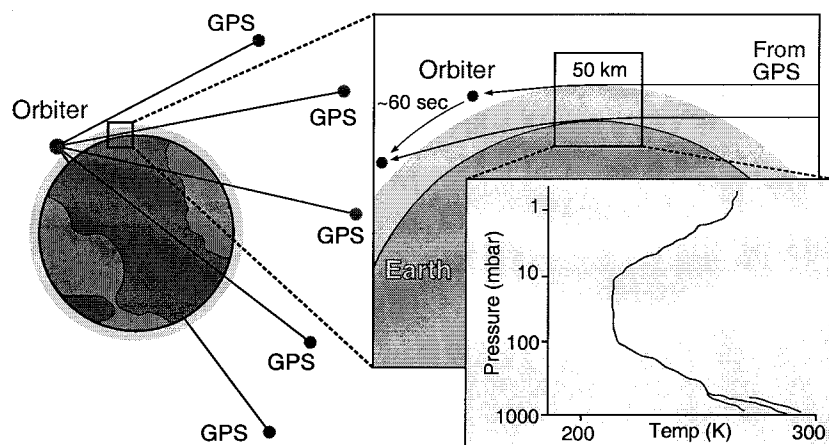
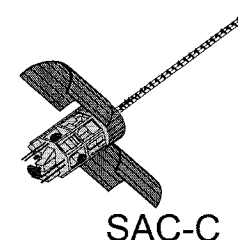
Key Features:

- 48 Parallel tracking channels
- Four L1/L2 antenna inputs
- Sub-millimeter phase precision
- Modular hardware and software
- Enhanced codeless operation
- Low cost fault-tolerant design



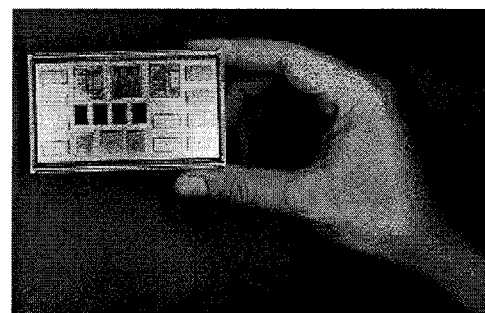
Principal Applications:

- Centimeter orbit determination
- Gravitational field mapping
- Atmospheric limb sounding
- Ionospheric imaging
- Bistatic ocean altimetry



GPS Atmospheric Limb Sounding

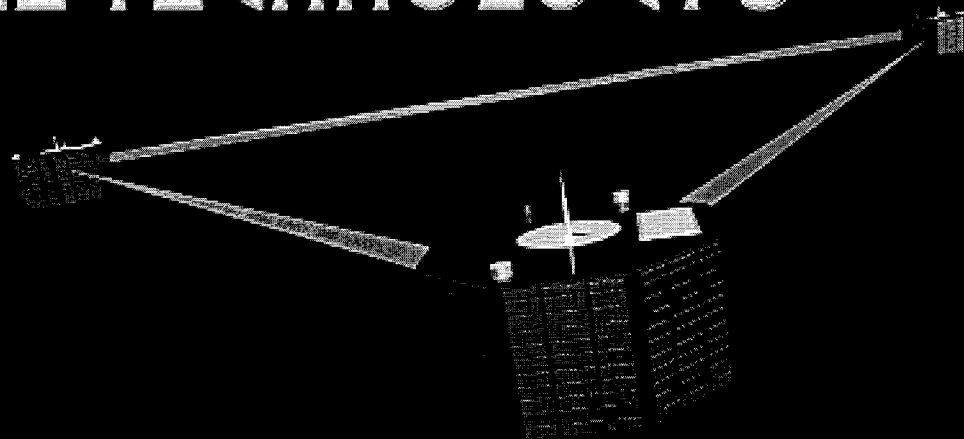
The Future:



"GPS on a Chip"



SPACE TECHNOLOGY 5



Space Technology 5, scheduled to launch in 2003, will attempt to fly three miniature spacecraft high above the Earth. Each of the spacecraft is about the size of a birthday cake and weighs about 21.5 kilograms (47 pounds). ST5 will be used to test methods for operating a constellation of spacecraft as a single system. The mission will also test eight innovative technologies in the harsh space environment near Earth's magnetosphere.

<http://nmp.jpl.nasa.gov/>

Space Technology 5

Nanosat Constellation Trailblazer Mission

Miniature Spacecraft

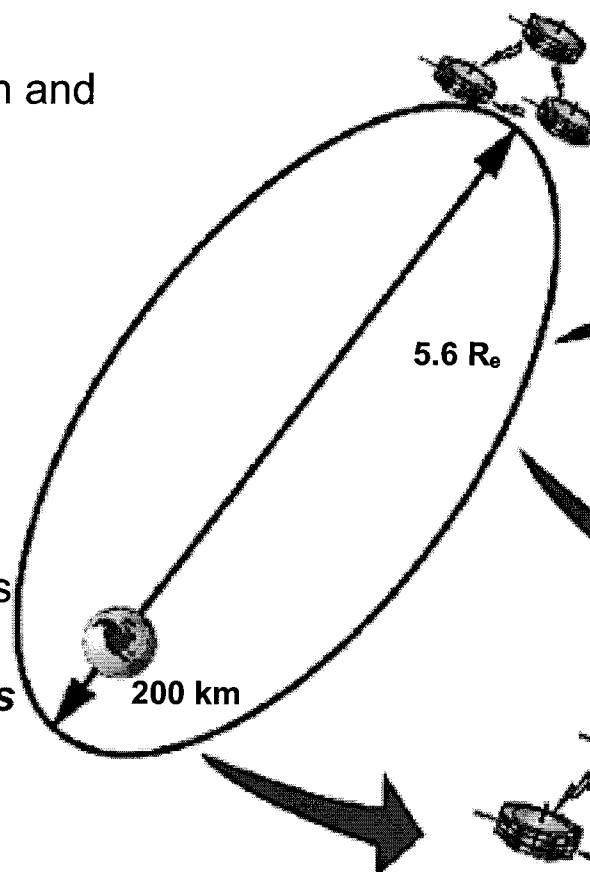
- Systems Design Integration and Test Technologies

Candidate Spacecraft Technologies

- 5V bus - 1/4V logic
- Li-Ion batteries
- Miniature transponder
- Miniature Thrusters
- Multi-functional structure
- Variable emittance coatings

Constellation Control, Coordination, and Operations Architecture

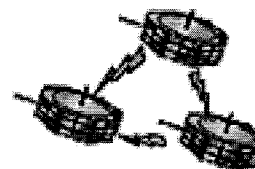
- Ground system autonomy
- Relative ranging
- Intra-constellation communications



Constellation Class Missions
Simultaneous, Multipoint, In-Situ Characterization of the Magnetosphere



Single Nanosats & Probes
Reduced Risk Small Spacecraft Bus for Low Cost Missions



Virtual Platforms
For Science Missions

TECHNOLOGY

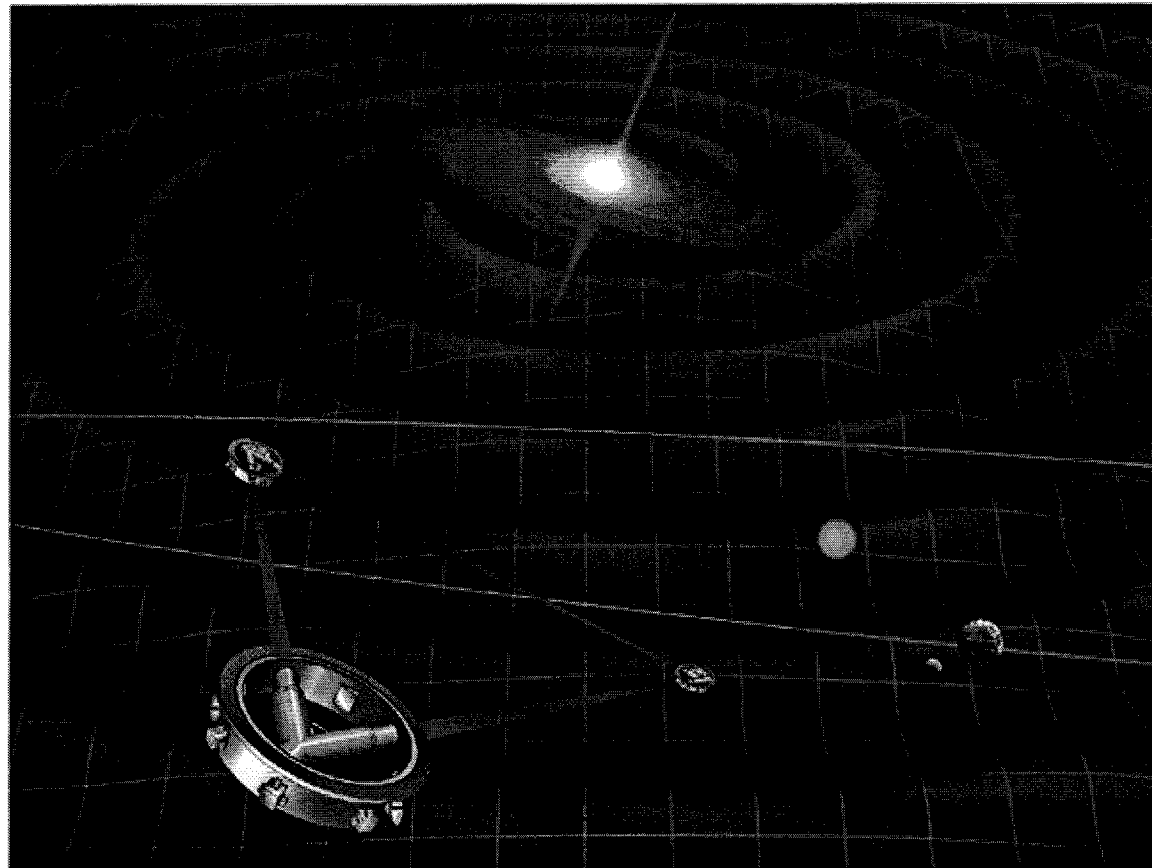


VALIDATION



INFUSION

Laser Interferometer Space Antenna (LISA)

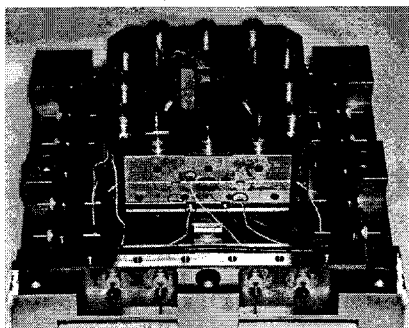
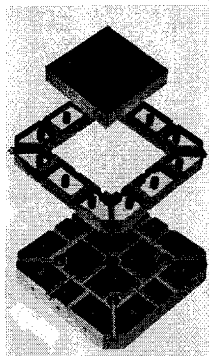


LISA Technology Drivers

Inertial sensors

Noise $< 10^{-16} \text{ g}$

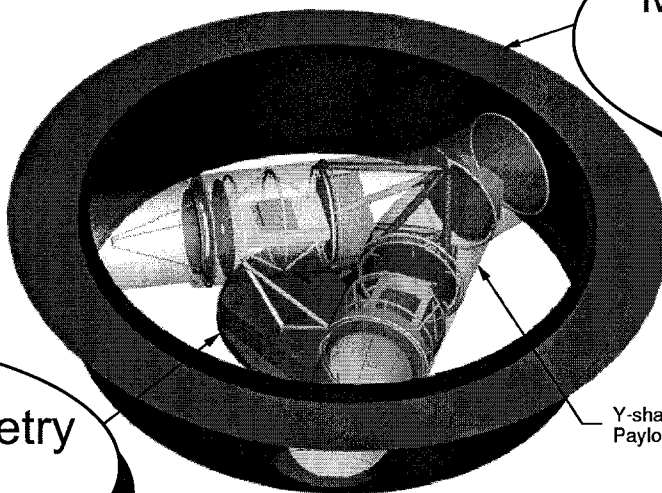
rms for 1000 s average



Micronewton thrusters

Range 1-100 μN

Noise $< 1 \mu\text{N}$



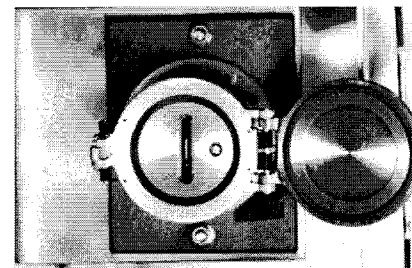
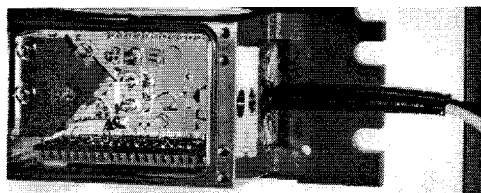
Y-shaped
Payload

Picometer interferometry

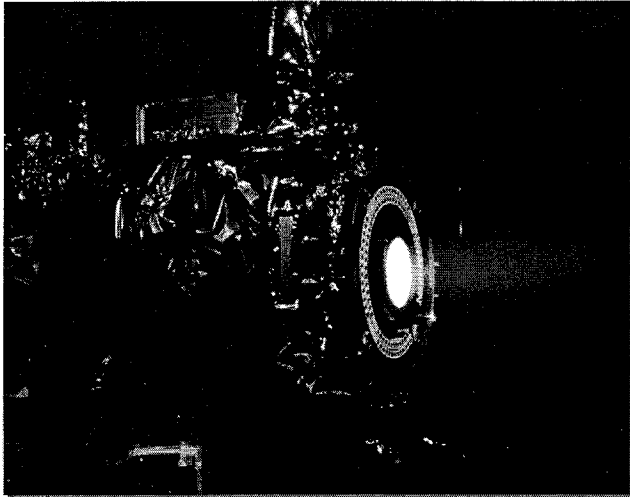
Accuracy $< 1 \text{ pm}$

rms for 1000 s average

1 W laser



Ion Propulsion System (IPS)



Description

Single-fault-tolerant, multi-engine Ion Propulsion System with significantly enhanced throughput capability and improved electronics packaging/thermal performance

Criticality

CNSR mission enabling. Current DS1 implementation of ion propulsion incurs unacceptable mass, performance, and thermal management penalties for CNSR.

Status

Major development effort initiated. Trade study identified the technology development path which provides the greatest mission benefit for the least development risk and cost.

Requirements

Increase engine throughput to > 2X NSTAR design point

Reduce system dry mass and cost

Develop a single-fault-tolerant system architecture

- higher reliability and fewer parts than ST4
- improved spacecraft packaging and thermal management

Develop system architecture flexible enough to be used by other SEP missions

Development Path

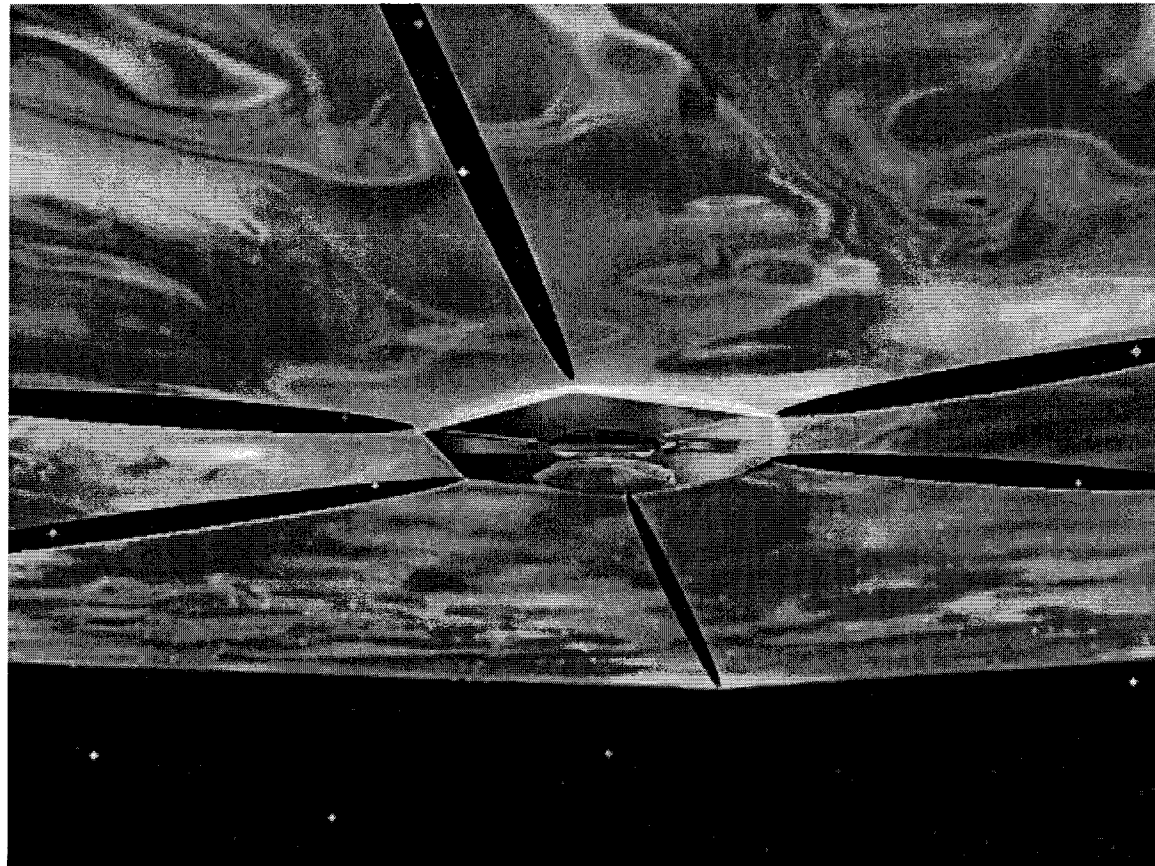
Initial Trade Space

Engine Power	Engine Throughput	System Architecture
2.3 kW (NSTAR)	80 kg	Conventional (one PPU operates one engine)
3.1 kW (enhanced NSTAR)	180 kg	
5.0 kW (new engine)	275 kg	Centralized High-Voltage and Neutralizer Functions

Working Design

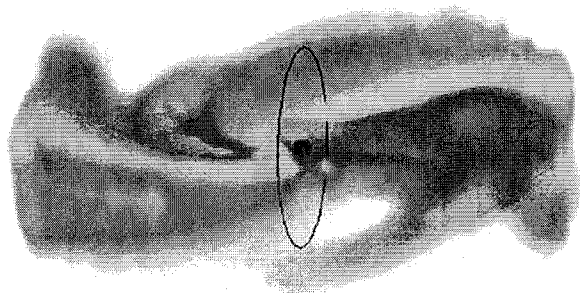
- 3.1 kW Enhanced NSTAR Engine
- 180 kW xenon throughput capability,
- Centralized high-voltage and neutralizer functions

Propellantless Propulsion



Solar Sailing

Solar Polar Imager



Mission Description

- **Example Mission Design**

- Launch: Taurus w/ Up.-Stg or Small Delta II
($C_3 = 0 \text{ km}^2/\text{s}^2$)
- Solar Sail Trajectory
 - * 4-5 Year Flight Time, 2 year OPS
- Final Orbit: 0.48 AU Solar Orbit with 60° Inclination
 - * 3:1 Resonance with Earth

- **Flight System Concept**

- 3-Axis or Spin-Stabilized Platform
- Solar Array Implementation

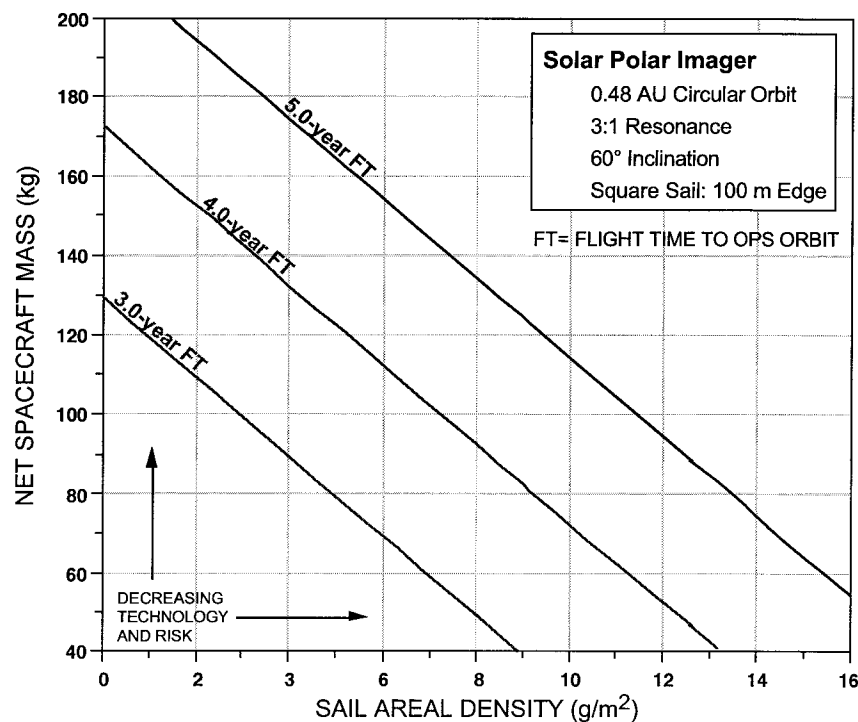
Technology Implications

- **Flight System Mass**

- Lower spacecraft mass allows **faster flight times** for **fixed sail technology** (maturity)
- Lower spacecraft mass allows for **reduced sail technology and risk** for **fixed flight time**

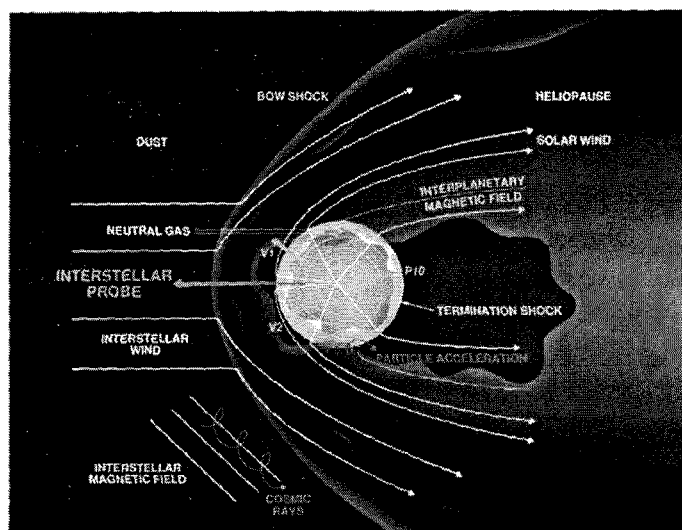
- **Project Cost**

- Lower spacecraft masses may allow for **consideration of cheaper launch vehicles**



Interstellar Probe

Spacecraft Mass & Solar Sail Challenge



Technology

- Solar Sail: $< 1 \text{ g/m}^2$, 200 m radius
- DSN 70m Subnet w/ Ka-band Uplink
- Next Generation ARPS
- Next Generation System On A Chip
- Ka-band S/C Components and Phased Array
- Hot-Gas Propulsion
- Micro-S/C Technology
- Low Mass/Power Instrumentation

Science Objectives

- Explore the interstellar medium and determine directly the properties of the interstellar gas, the interstellar magnetic field, low energy cosmic rays, and interstellar dust
- Determine the structure and dynamics of the heliosphere, as an example of the interaction of a star with its environment
- Study, in situ, the structure of the solar wind termination shock, and the acceleration of pickup ions and other species
- Investigate the origin and distribution of solar system matter beyond the orbit of Neptune

Mission Description

- **Example Mission Design**
 - Delta II 7425 Launch (719 kg Cap., $C_3=0 \text{ km}^2/\text{s}^2$)
 - Flight System Launch Mass: 564 kg
 - Solar Sail Trajectory Targeted for Nose of Heliosphere
 - * 0.25 AU Solar Pass, 200 AU in 15 years
- **Flight System Concept**
 - "Flying Antenna" Design Implementation (191 kg)
 - Sized for 30 year Operations
 - Payload: Fields & Particles + Imaging

Measurement Strategy

- Measure, in situ, the properties and composition of interstellar plasma and neutrals, low energy cosmic rays, and interstellar dust
- Determine the structure and dynamics of the heliosphere with in situ measurements and global imaging
- Map the infrared emission of the zodiacal dust cloud, measure in situ the distribution of interplanetary dust, and determine the radial distribution of small Kuiper Belt objects

Probing Interstellar Space

Miniaturization Effect on Flight Time

Sail Performance Trade: T_f , S/C Mass, Perihelion with Sail Technology

